

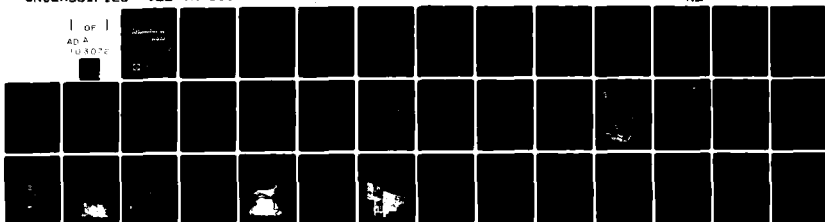
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## CIVIL ENGINEERING LABORATORY

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## INTRODUCTION

In 1975 the Naval Facilities Engineering Command (Code 03) tasked the Civil Engineering Laboratory with finding a way to reduce the rising costs associated with the disposal of dredged materials.

There are 12 Navy harbors in the Continental United States that have an annual maintenance dredging burden in excess of 100,000 cu yd per year. These are listed in Table 1, along with the amount and type of sediment removed and the references used as sources for the dredging data. These data show that 87% of the material is cohesive sediment and 13% is sand. Figures 1 through 17 show harbor configurations and the location of actual dredging.

A review of the figures shows that Navy harbors are typically located along inland waterways with the berths formed by piers extending from shore. Over two-thirds of the area that requires dredging with Navy funds is contained within these quiet water, cul-de-sac, berths. The piers which form these berths are effective barriers to water circulation because mud builds up under the piers due to the turbulence caused by the pilings. Turbulence in the water increases the rate of collisions of suspended clay particles and aggregates. This localized area of increased particle size (and, therefore, increased settling rate) becomes an area of preferred deposition. Sediments accumulate under the pier to a height somewhere between low and high tide depending on the strength of the tidal currents created by the berth's tidal prism. These berths, unfortunately, are sediment-settling basins where deposits build up, and currents are not generated with sufficient strength to resuspend the sediment.

Dredging costs have risen dramatically along with and because of the national concern for environmental quality. Estuarine mud, contaminated with heavy metals and other potential pollutants, composes 87% of the material dredged by and for the Navy.

The heavy metals occur naturally in rivers through the erosion of the sediment and rock making up the watershed. When freshwater from these rivers begins to mix with seawater, flocculation occurs. Many Navy harbors are located along waterways where this mixing takes place, and not only is suspended sediment deposited, but so are the heavy metals because of their affinity to the clayey flocs.

Typically, Navy berths are located within estuaries (tidal rivers). Sediment carried by these rivers is held in suspension while the water is fresh, but when mixed with seawater, flocculation occurs resulting in deposition with rates as high as 2 cm a day. The sediments are carried into Navy quiet subsequently resuspended. These sediments, upon flocculation, concentrate heavy metals. Further contamination may result from sand blasting, paint removers, oil spills, and other shipyard and harbor activities. Relocating these contaminated deposits pollutes the disposal site, imposing additional costs to measure the amount of pollution and to minimize its effect.

Approximately 13% of the material dredged with Navy funds is sand. Sand deposition occurs in high energy environments such as in harbor entrances where jetties cross the ocean's surf zone. Energy is so high that mud size (clay and silt) sediments are washed away leaving deposits of sand. Sand is rarely contaminated because it is chemically inert.

Navy harbors with an annual maintenance dredging burden of 0.1 M cu yd/yr or more are described below. A figure in each case provides the location and configuration of the harbor and the areas where maintenance dredging recurs. Causes of sedimentation are discussed briefly, as is the method of removal and the type and location of the spoil site. Information on current velocities, physical properties of the water, sedimentary analyses, contamination levels, dredging histories, etc., are contained in References 1 through 21 listed in Table 1.

The customary U.S. units of measurement used in this report can be converted to metric (SI) units as follows: multiply cu yd by 0.7646 to obtain cu m, multiply mi by 1.6093 to obtain km, and multiply ft by 30.48 to obtain cm.

#### MARE ISLAND NAVAL SHIPYARD

Mare Island Naval Shipyard is located along the southwest side of Mare Island Strait which is formed by the Napa River where it enters San Pablo Bay (Figure 1). The high siltation rate in Mare Island Strait has attracted many students of clay sediment deposition, notably Krone (Ref 1), and the U.S. Army Corps of Engineers (Ref 2).

Of the 10 M cu yd of sediment dredged annually (10 M cu yd/yr) from the San Francisco Bay system, 3 M cu yd are dredged from this small area (Figure 2). Studies by Krone and others have shown that Mare Island Strait is not typical of estuarine deposition, because the source of the Mare Island Strait deposits is not the suspended load carried by the Napa River. Rather, the sediment source is San Pablo Bay where sediment is deposited by the Sacramento and San Joaquin Rivers. After flocculation and deposition the sediment is resuspended and carried into Mare Island Strait by flooding tidal currents.

An Army hopper dredger maintains Mare Island Strait to a depth of 32 ft and dredges to within about 200 ft of the finger piers and bulkhead quay at the shipyard.

The present annual maintenance dredging burden to the Navy at Mare Island Naval Shipyard is about 0.5 M cu yd. Dredging is done annually at the Finger Pier berths and along the quay wall north of the Finger Piers (Figure 2); Piers 34 and 35 at the south end of Mare Island are subject to dredging on an as-required basis. Dredging is mostly accomplished by a Navy-owned-and-operated 16-in. hydraulic dredge which normally works 16 hr a day to maintain the berthing areas. Occasionally, some dredging is done by contract. The dredged material is pumped through large permanent pipelines to leveled disposal sites along the western shore of Mare Island.

The sediment dredged from Mare Island Strait is typical of the mud dredged throughout the San Francisco Bay area. It is 46% silt, 42% clay, and 12% sand. San Francisco Bay mud is fairly uniform throughout the Bay system. The mud is soft, plastic, black-to-grey, silty clay, or clayey silt.

## ALAMEDA NAVAL AIR STATION

Alameda Naval Air Station, located directly across San Francisco Bay from San Francisco (Figure 1), usually requires annual dredging of 0.9 M cu yd of typical San Francisco Bay mud (Figure 3). Dredging is handled by the Western Division (WESTDIV) of the Naval Facilities Engineering Command. WESTDIV arranges for contractors to dredge Alameda, and the spoil is usually disposed of in San Francisco Bay near Alcatraz. On rare occasions the mud's contamination level requires ocean dumping.

Two kinds of depositional mechanisms account for Alameda's high siltation rate. The approach channel to the Carrier Basin has been dredged across open mud flats to a depth of 42 ft, and is only partially protected by breakwaters along its 2-mi length.

Winds and tidal currents sweep back and forth across the channel where wave-suspended sediment is deposited. Some of these sediments are carried by southerly setting flood currents into the carrier basin itself. Unfortunately, a 750-ft seaplane crossing gap in the south breakwater allows flow through the turning basin. The result is that a volume of water far in excess of the tidal prism enters the basin, slows down enough to drop its sediment load, and flows out to the south.

Closing the breakwater gap in model studies prevented 18% of the sediment accumulation in the carrier basin. Plans have been made to close the gap because it is no longer needed.

## MOLATE POINT NAVAL FUEL DEPOT

The Molate Point fuel pier, located in the Central Bay of the San Francisco Bay System (Figure 1), has suffered high siltation rates over the years reaching as high as 10 ft/yr accumulation after dredging. Average rates are about 2.5 ft/yr on the west side of the pier head and 1.5 ft on the east side (Figure 4). This high siltation rate has been studied by Dames and Moore (Ref 7). Reasons given for high siltation rates were: (1) tidal currents sweeping bay water with high suspended sediment concentrations into the piles supporting the fuel pier causing aggregation and deposition there, (2) bottom roughness producing the same effect, and (3) abrupt shoaling near the fuel pier.

The material is typical San Francisco Bay mud, and is spoiled in the Alcatraz Deep. Dredging is by private companies under contract to WESTDIV.

The fuel pier was dredged to a depth of 35 ft in early 1980 followed by smoothing the bottom by dragging an H-beam over the area dredged. Three possible solutions to the high siltation rate considered too costly to pursue were: (1) extending the pier into deeper water, (2) removing as many piles as possible, and (3) installing streamlining appurtenances to either end of the fuel pier's north-south head.

## PORT HUENEME

Port Hueneme is a small coastal town in California 70 mi north of Los Angeles. The construction of Port Hueneme Harbor was initiated in 1938 by local growers and finished in 1942 by the Navy (Figure 5).

Before its construction, sand moved down the coast unrestricted. After harbor construction, it became necessary to dredge and transport sand from northwest of the jetties to prevent denudation of Port Hueneme public beaches. Realizing that this dredging was inevitable, in order to make the most of the dredging, the Channel Islands Harbor was constructed up coast. The result is that by moving the sand to the other side of Port Hueneme Harbor, the Channel Islands Harbor is also maintained without additional dredging.

The dredging of two million cu yd of sand from around the Channel Islands Harbor occurs every 2 yr and is pumped through pipelines onto the beaches southeast of Port Hueneme Harbor. The Navy's share of the expense is 19%, or stated in volume dredged, 0.19 M cu yd/yr.

#### NEW LONDON NAVAL SUBMARINE BASE

The New London Naval Submarine Base is located in Connecticut along the eastern bank of the Thames River. It became operational in 1979 for the SSN 688 class submarines after extensive dredging in order to deepen and widen the Thames River (Figure 6). Dredging required to maintain project depths for the SSN 688 class submarines (36 ft at some piers and 39 ft at others to lessen dredging frequency) has been estimated to be 0.1 M cu yd/yr.

Samples taken in the area to be dredged are primarily silt: clayey silt and sandy silt. The dredged mud will be disposed of at a designated spoil site in Long Island Sound. Dredging will be by contractor arranged for by NORTHDIV.

#### NAVAL WEAPONS STATION EARLE

Naval Weapons Station Earle, located in Sandy Hook Bay, N.J. (Figure 7), is dredged every 5 yr when 1 M cu yd of mud is removed from the area. An ocean dump site is utilized. The siltation problem consists primarily of an unprotected dredged channel and turning basin (Figure 8) susceptible to transverse currents transporting suspended sediment. Fortunately, the suspended sediment load is low. The Leonardo Piers shown on Figures 7 and 8 do not aggravate the siltation rate because aggregation is not a principal factor as it is in the comparable construction at the Molate Point fuel pier in San Francisco Bay.

#### PHILADELPHIA NAVAL SHIPYARD

The Philadelphia Naval Base is located at the confluence of the Delaware and Schuylkill Rivers on a man-made peninsula (Figure 9). Of the Naval facilities located there, only the Philadelphia Naval Shipyard requires maintenance dredging.

The Delaware River is tidal and saltwater intrudes to the Philadelphia area. As a result, over 10 M cu yd are dredged annually from the main channel of the Delaware. The average annual Navy requirement is 0.2 M cu yd. Dredged material is silt-clay which is disposed of in designated spoil sites along the banks of the Delaware River.

Navy dredging is conducted in the berths and along the wharves of the shipyard and in the reserve basin by private companies contracted by NORTHDIV. The Corps of Engineers disposal site is available to the Navy on an amortization cost per cubic yard basis.

#### NORFOLK NAVAL STATION

Norfolk Naval Station is located in one of the largest (25 sq mi) naturally protected harbors in the world, Hampton Roads, Va. The harbor is formed by the confluence of the James, Nansemond, and Elizabeth Rivers (Figure 10). The Naval Station, which includes the Destroyer/Submarine Piers adjacent and to the south, accounts for the bulk of the Navy's dredging burden in the Hampton Roads area.

The Naval Station and adjoining Naval Air Station and minor host activities, including Naval Supply Center, Naval Air Rework Facility, and Navy Public Works Center, comprise the Sewell's Point Area Navy Complex. Other local Navy activities with waterfront facilities include Norfolk Naval Shipyard, Portsmouth; Naval Amphibious Base, Little Creek; Naval Weapons Station, Yorktown; and Naval Supply Center - Cheatham Annex, Williamsburg. However, 90% of the composite dredging at these facilities is done at the Norfolk Naval Station.

The clay-silt dredged at Norfolk is similar to Mare Island Strait mud. The Elizabeth River is the main source of sediment with possible contributions from the James and Nansemond Rivers. The highest shoaling rate (2-1/2 ft/yr) in the area occurs in the carrier berths flanking Pier 12 (Figure 11). Dredging is contracted for by the Atlantic Division, Naval Facilities Engineering Command (LANTNAVFACENGCOM). The hydraulically dredged spoil is pumped by pipelines to Craney Island for disposal (Figure 10).

#### CHARLESTON NAVAL BASE AND WEAPONS STATION

The Naval bases requiring dredging in the Charleston, S.C., area are both located along the lower reaches of the Cooper River just north of Charleston (Figure 12). The Cooper River is a stratified estuary from the Naval Station seaward.

Dredging is accomplished at the Naval Base by a Navy-owned-and-operated dredge. Spoil is pumped beneath the Cooper River to upland, dyked spoil sites. The dredging is done on an as-needed basis without before-after depth surveys to determine the amount dredged. Dredging volumes are estimated by applying a dredging rate to the operating time. This procedure resulted in a tendency to overestimate annual volumes. Navy estimates for annual maintenance dredging at the Naval Base ranged from 3 to 5 M cu yd (Ref 15), and the Corps of Engineers' estimate was 3 M cu yd (Ref 11). Based on recent analyses, Charleston Naval Shipyard's estimate of the Navy's annual maintenance dredging burden in the Charleston area is 1.7 M cu yd (Ref 16). The material is silty clay.

The Navy is also responsible for the maintenance of 18,000 ft of the common use channel in the Cooper River from Goose Creek to wharf Alpha at the Naval Weapons Station (Figure 14). Maintenance depth is 35 ft. Dredging is on a yearly basis, conducted by contracting through the Corps of Engineers.

The Naval Weapons Station also requires Navy-funded dredging every other year by contracting through the Corps of Engineers.

According to Cunningham (Ref 14), two years ago the COE undertook a 4-yr project to redirect the Santee and Cooper Rivers to their pre-1942 discharge regimens.

Prior to 1942, the average flow of the Cooper River was 72 cfs. In 1942, a hydroelectric project was completed that diverted water from the Santee River watershed to two new lakes, Moultrie and Marion, for flow over the Pinopolis Dam and into the Cooper River. After 1942, the average Cooper River discharge became 15,600 cfs, and the dredging requirements in Charleston Harbor increased by a factor of 20.

In 1982, when the redirection is completed, the Cooper River is expected to have an average discharge rate of 3,000 cfs. This, it is estimated, will eventually cut the present Navy dredging burden by a factor of 3.

#### KING'S BAY TRIDENT BASE

King's Bay is in Georgia 4 mi north of the St. Marys River which marks the Georgia-Florida border. Downtown Jacksonville is 40 mi south. King's Bay is being made into a Navy Base which will accommodate the Poseidon class submarines, and eventually the Trident class. Extensive dredging (about 12 M cu yd) has been completed, taking the St. Marys' entrance channel to 40 ft MLW, and the approach channels through Cumberland sound to 38 ft MLW (Figure 15).

There is no dredging history involving these new depths, but the Army Corps of Engineers estimates that the annual maintenance dredging volume will be 2.0 M cu yd, 1.4 M mud and 0.6 M sand. The Naval Base estimates 2.2 M cu yd/yr (R. A. Currier personal communication, 19 Nov 1980). Fine-grained sediment is expected in the vicinity of the base itself, while sand will have to be dredged west and east of the jetties.

The jetties that form the ocean entrance and St. Marys' entrance channel are permeable to sand transport. This, coupled with a large tidal excursion maximum of 9 ft, causes migrating beach sand to be jettied seaward to form a tidal bar off the end of the jetties. If the jetties are extended seaward to accommodate Trident class submarines, the tidal bar will move out proportionally, making down-coast beach nourishment even more difficult.

#### MAYPORT NAVAL STATION BASIN

Mayport, Fla., is located in greater Jacksonville and is flanked by the Atlantic Ocean to the east and the St. Johns River on the north. The Mayport Naval Station is a major base, homeporting over 30 ships including two aircraft carriers in the Mayport Naval Basin. Mayport Naval Basin is situated immediately south of the St. Johns River, allowing ships to reach the open waters of the Atlantic after only a 2-mi run (Figure 16).

Being close to the sea with a large tidal range, the tidal currents generated in the St. Johns' commercial channel are strong (2 to 3 kn). These strong currents account for the sand that is dredged from the

channel. However, the Mayport Basin accumulates silty sediment, 0.6 M cu yd/yr. Because of this, the basin was modeled by the Army Corps of Engineers at the Waterways Experiment Station in order to determine the cause of the fine-grained deposition and ways to decrease it. Although the cause of fine sediment deposition was not identified in the model report (Ref 19), the impact of various reconfigurations of the Wards Bank training wall, which separates the basin from the river, was documented. The change which produced the largest beneficial effect was extending the training wall an additional 1,900 ft. In the model this simulated extension decreased basin deposition by 47%.

Subsequently, members of a Scripps Institution of Oceanography survey team observed the generation of large harbor entrance eddies in the St. Johns River and the migration of these eddies into the Mayport Basin. Additional field work is planned in order to quantify the shape, size, and dynamics of the eddies which apparently are generated by the termination of the Wards Bank training wall. Presumably these eddies migrate into the basin where they lose their momentum and suspended load.

Removal of dredge material was by pipeline dredging in 1963-69 with disposal in Navy-owned wetlands. Since 1969, wetlands disposal has been discontinued and removal of material has been by Army hopper dredge on an "as-available" basis, using ocean disposal of spoil. However, the next dredge fill for Naval Station Mayport will go to level the upland spoil site. The offshore spoil site is still open and EPA approved, but the EPA permit is for land disposal only. See DREDGING COSTS section of this report for a discussion of spoil sites in the Mayport area.

#### PORT CANAVERAL

Port Canaveral, Fla., originally consisted of a channel, dredged in 1951-1952, to connect the Banana River to the Atlantic Ocean. This channel is bordered on the north by the Cape Canaveral Air Force Station, and on the south by the city of Cape Canaveral. The port has been gradually enlarged over the years with the largest growth culminating in 1976 with the completion of construction work to accommodate Trident submarines. About 14 M cu yd were dredged in 1975-1976 to construct a 100-acre turning basin and to deepen and extend the entrance channel. Project depths are: turning basin, 41 ft; entrance channel, 44 ft.

Maintenance dredging of the Port Canaveral Main Ship Channel is conducted annually by Hopper Dredge utilizing ocean disposal of dredged material. During the 1980 maintenance dredging, in a joint National Marine Fisheries-Corps of Engineers effort, the main ship channel was cleared of sea turtles by netting and relocating the turtles.

The TRIDENT Turn Basin is currently planned for maintenance dredging every seven years. Dredged material is placed in two land spoil areas, one on the west side and one on the east side of the Turn Basin. Based upon rather limited historical data, it appears that the Turn Basin shoals evenly at a rate of 0.6 ft/yr. Two feet of advanced maintenance dredging has been employed to decrease the frequency of dredging and to thus minimize the cost per cubic yard of mobilization-demobilization (Ref 21).

## DREDGING COSTS

Although dredging costs have been rising markedly with accelerating inflation, fuel costs, and the proliferation of environmental protection regulations, in 1980 the trend was apparently reversed by the addition of new competition to the market place. On April 26, 1978, President Carter signed Public Law 95-269, amending the acts of August 11, 1888 and March 2, 1919 pertaining to the Army's role in carrying out projects for improvements of rivers and harbors by dredging. Public Law 95-269 dictates that the Secretary of the Army will have dredging projects carried out in a manner most economical and advantageous to the United States. The Army Corps of Engineers following this Congressional mandate, began to compete with private dredging contractors in bidding on dredging jobs which previously had been exclusively Army work.

Dredging costs in Navy harbors are influenced by the following factors:

1. The volume dredged per specific job is of prime importance. The cost of mobilizing and demobilizing equipment is always significant, but on low-volume jobs it becomes dominant, whereas on large-volume jobs mobilization/demobilization can be absorbed for a few pennies per yard. For example, in 1980 the cost of dredging and pumping 2 M cu yd of sand around Port Hueneme Harbor was \$2,700,000 or \$1.35 per yard. The mobilization/demobilization cost was \$500,000, adding 25 cents to the cost of each cubic yard dredged and transported (Ref 8). The sand collection area (Figure 5) was designed to contain a 2-yr accumulation, thus the dredging frequency.
2. The proximity of the spoil site to the dredge site is an important factor. Long runs to sea for ocean dumping of polluted spoils, or unavailability of local upland or riparian spoil sites, can have major impact on the cost of dredging. Fortunately, the Navy has not been required to any large extent to use ocean spoil sites. Of the 12 harbors listed in this atlas, only Naval Weapons Station Earle and the New London Naval Submarine Base regularly spoil at sea. In the case of Earle, ocean dumping is the least expensive alternative, and New London only involves 0.1 M cu yd/yr. There is a good possibility that dredging of the Mayport Basin will soon require ocean dumping. The problem is that upland spoil sites are almost full, and further use will require raising the dyke elevation. In this case Army Corps of Engineers estimates for dredging Mayport and spoiling in the ocean versus upland spoil areas are comparable.

For removing 2.1 M cu yd of silt from the Mayport Basin and transporting it to an ocean dump site, the cost estimates break down to (Ref 14):

\$ 260,000	Mobilization/Demobilization
4,935,000	Dredge, transport, and dump
	@ \$2.35/cu yd
20,000	Environmental monitoring of the
	dump site
224,000	Design cost
<u>210,000</u>	Supervision
\$5,749,000	TOTAL ÷ 2.1 M cu yd = \$2.74 cu yd

Although environmental conditions appear here to add only \$20,000 to the cost of dredging, environmental safeguards weigh much more heavily than the figures indicate. The figures mean that enlarging a spoil site to Environmental Protection Agency standards (raising the dyke elevation) is comparable in cost to transporting the material to the ocean.

3. In addition to the environmental costs referred to above, preparation of Environmental Impact Statements (EIS) or Reports (EIR) is costly, as is conducting elutriate and bioassay tests. But the cost of these items usually does not increase the cost per cu yd of dredged material significantly, at least for harbors with a heavy maintenance dredging burden such as described in this atlas. For instance, the upland spoil sites in the Charleston area require a surcharge of only 5 cents per cu yd of material dredged to maintain them (Ref 14).

The requirement for assessing environmental impacts is aimed primarily at new construction where, for instance, a river is dredged deeper than ever before. Assessing the environmental impact of this type of activity can be very expensive, such as it was in deepening and widening the Thames River to expand the capabilities of the New London Submarine Base. But once new construction dredging has been accomplished, maintenance dredging simply keeps returning the environment to a condition lawfully judged to be acceptable.

Elutriate tests average around \$600.00 per sample, and if the dredged material does not successfully pass the elutriate test, then bioassay tests must be conducted which can exceed \$15,000.00 per sample. The Environmental Protection Agency requires bioassay tests for ocean dumping. These tests, though expensive, do not account for significant costs to the Navy when averaged over the 10 M cu yd dredged annually.

4. The price of fuel is rapidly becoming a factor. In April 1980, the price per gallon of diesel fuel was a dollar, having just doubled in cost. At this price, diesel fuel is approaching 20% of the cost of dredging on the average.

5. Competition is an important factor as mentioned above.

6. Harbor configuration is important. Since the 1980 Congressional mandate, the Army Corps of Engineers and industry keep most navigable waterways open for commerce. This includes most ocean-jettied harbor entrances. The Navy is required to dredge waterways only when they are used exclusively by the Navy, or where the waterway depth requirement is exclusively tailored for Navy use. Examples of this are portions of the ocean entrance and common use inland waterway at King's Bay, and the entrance to Port Canaveral where extra depth is required because of the deep draft Trident class submarines.

Most Navy dredging takes place in close quarters around berths and docks because over two-thirds of Navy dredging is confined to quiet water, cul-de-sac berths. Quite often this requires using clam-shell dredging (such as is used at NAS Alameda). This type of dredging is costly and can add as much as \$1.00/cu yd dredged, as it does at NAS Alameda.

## COST SUMMARY

Among the lowest dredging prices per cu yd in the Navy harbors discussed in this atlas is NWS Earle; 1 M cu yd of relatively unpolluted fine-grained sediment is dredged every 5 yr and spoiled nearby at a cost of \$1.00/cu yd (Ref 9). At the other extreme, Mayport dredging and ocean dumping is estimated to cost \$2.74 cu yd (Ref 7). To this must be added the expense of pre- and post-dredge surveys and the expense of employees at Mayport and NAVFAC's Southern Division who are salaried to work on various aspects of dredging: EIS's, surveys, contracting, etc.

In early 1980, MINSY estimated dredging costs to be \$2.00/cu yd (Ref 22). The highest per cu yd cost in dredging Alameda last year was \$1.87/cu yd for clam-shell work close in the piers and wharves (Ref 23). Charleston Navy Yard's highest cost, \$1.56/cu yd (Ref 14), is comparable.

These figures suggest that the average cost per cu yd for the Navy's maintenance dredging in 1980 is comparable to a 1978 estimate, \$2.50/cu yd (Ref 22). Meanwhile, the Navy's total dredging volume estimate has been revised from 12 M cu yd/yr (Ref 24) to 9 M cu yd/yr. Thus, the Navy's total annual maintenance dredging expenditure is estimated to be \$23 M versus the \$30 M reported in Reference 24.

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Table 1. Listing of 12 Navy Harbors With Annual Maintenance Dredging  
Averages and Sediment Types Based on References Shown

Harbor	Annual Maintenance Dredging (M cu yd)	Reference	Sediment Type	Reference
Mare Island Naval Shipyard	0.5	1,2,4,5,6	Mud	3
Alameda Naval Air Station	0.9	2,4,5	Mud	3
Molate Point Naval Fuel Depot	0.12	4,7	Mud	3
Port Hueneme Harbor	0.19	8	Sand	8
New London Naval Submarine Base	0.1	9,10	Mud	9
Naval Weapons Station Earle	0.2	9	Mud	9
Philadelphia Naval Shipyard	0.2	11,12	Mud	11,12
Norfolk Naval Station	0.38	11,13	Mud	13
Charleston Naval Base & Weapons Station	1.7	6,11,14,15,16	Mud	11
King's Bay Trident Base	2.0-2.2	17	70% Mud 30% Sand	17
Mayport Naval Station Basin	0.6	14,18,19,20	Mud	18,19
Port Canaveral	0.15	20,21	Sand	20
Miscellaneous	2.0	11	-	

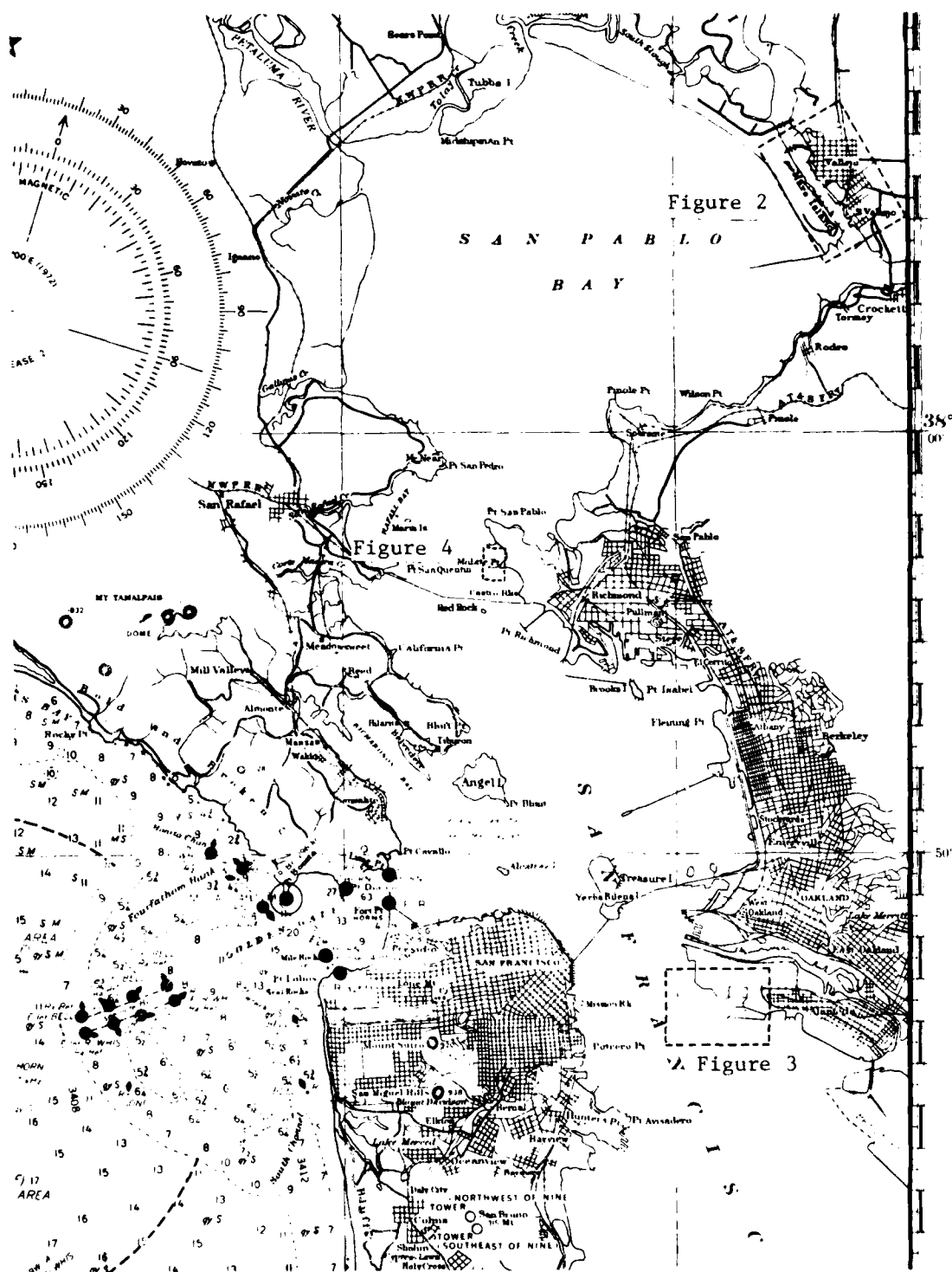


Figure 1. Location map of Mare Island Naval Shipyard (Figure 2), Alameda Naval Air Station (Figure 3), and Molate Fuel Pier (Figure 4) (from NOAA Chart 18640).

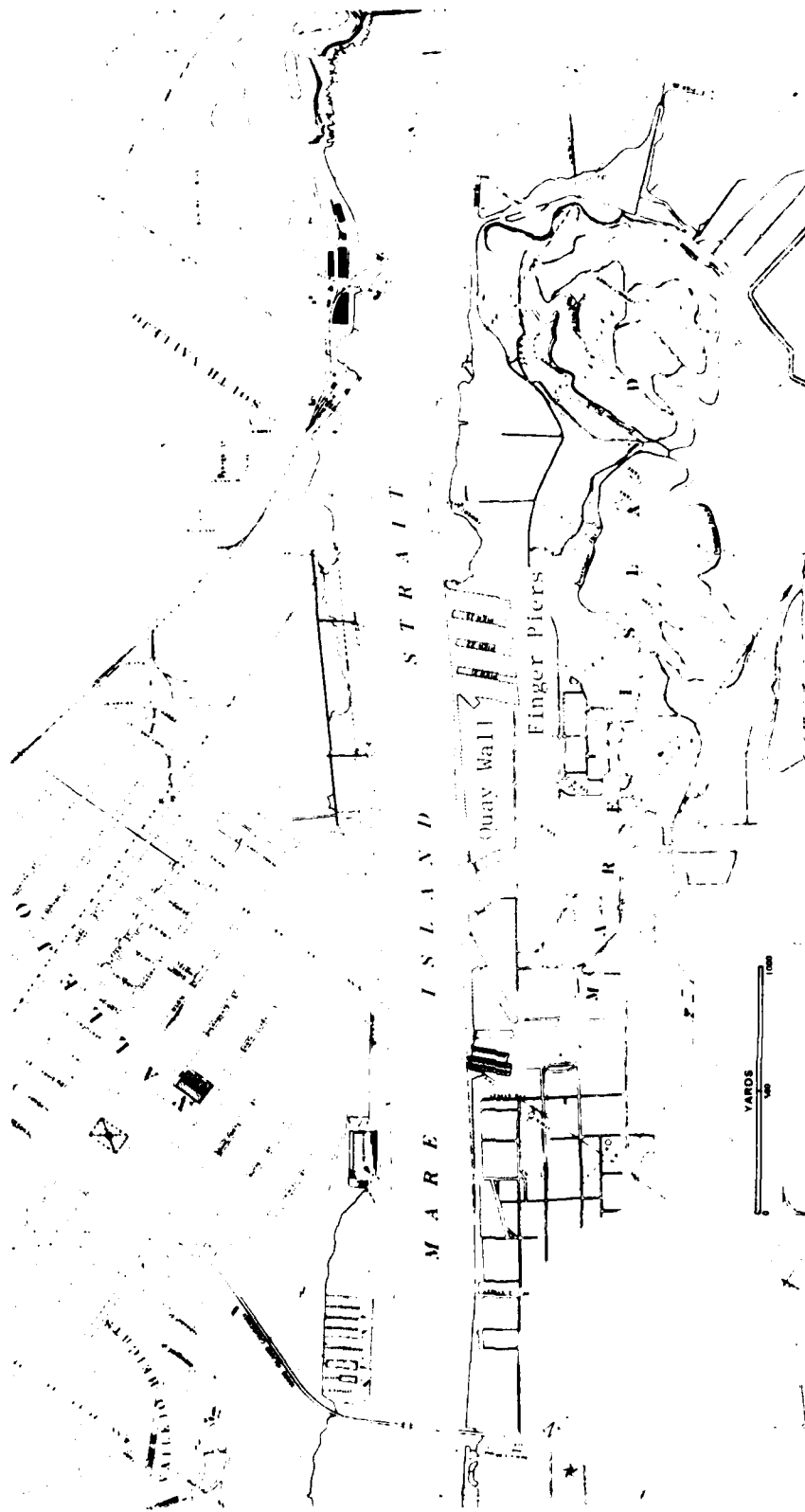


Figure 2. Mare Island Naval Shipyard showing dredging in the four Finger Pier berths and along the quay wall (from NOAA Chart 18655; see Figure 1).



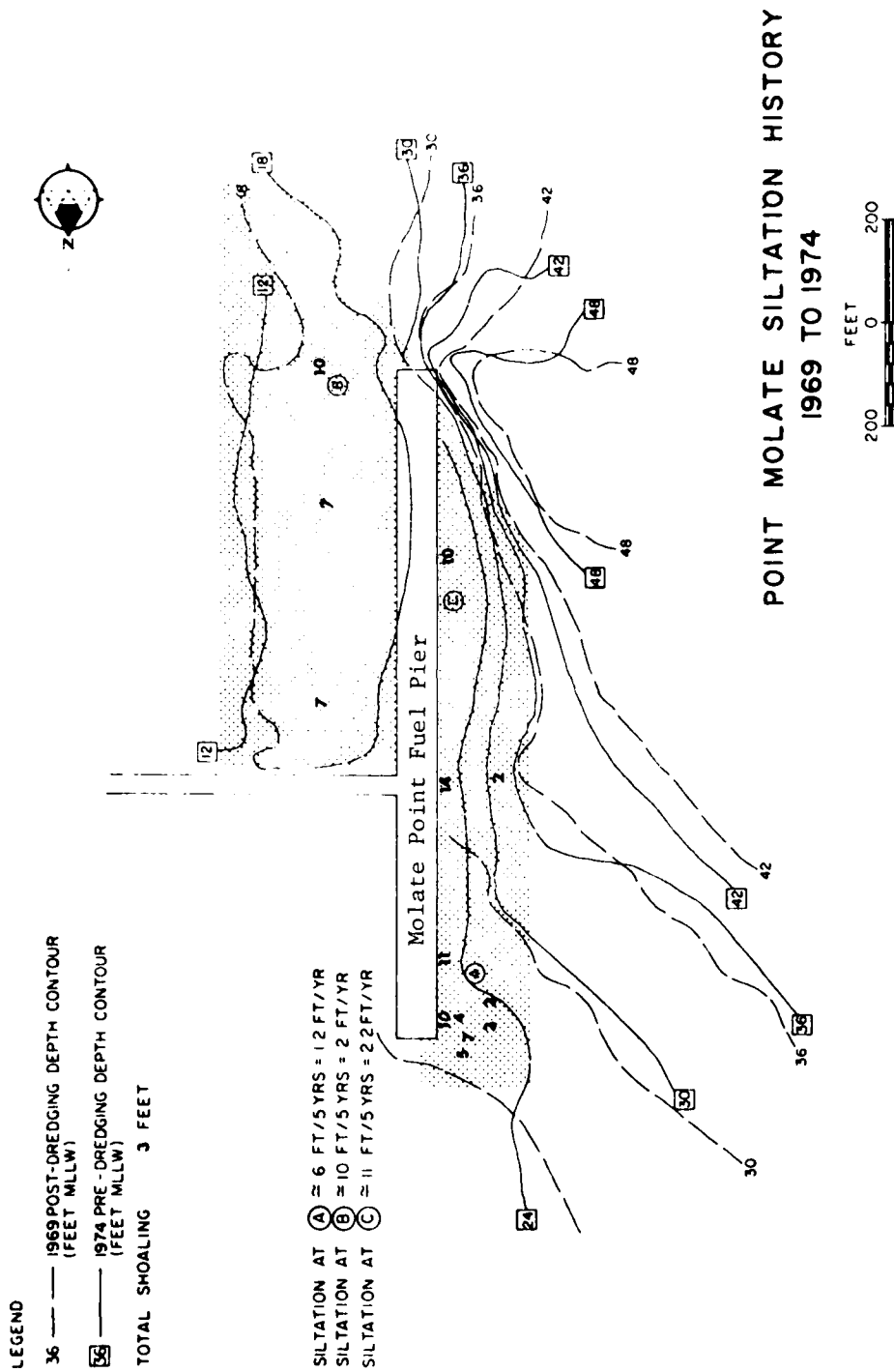
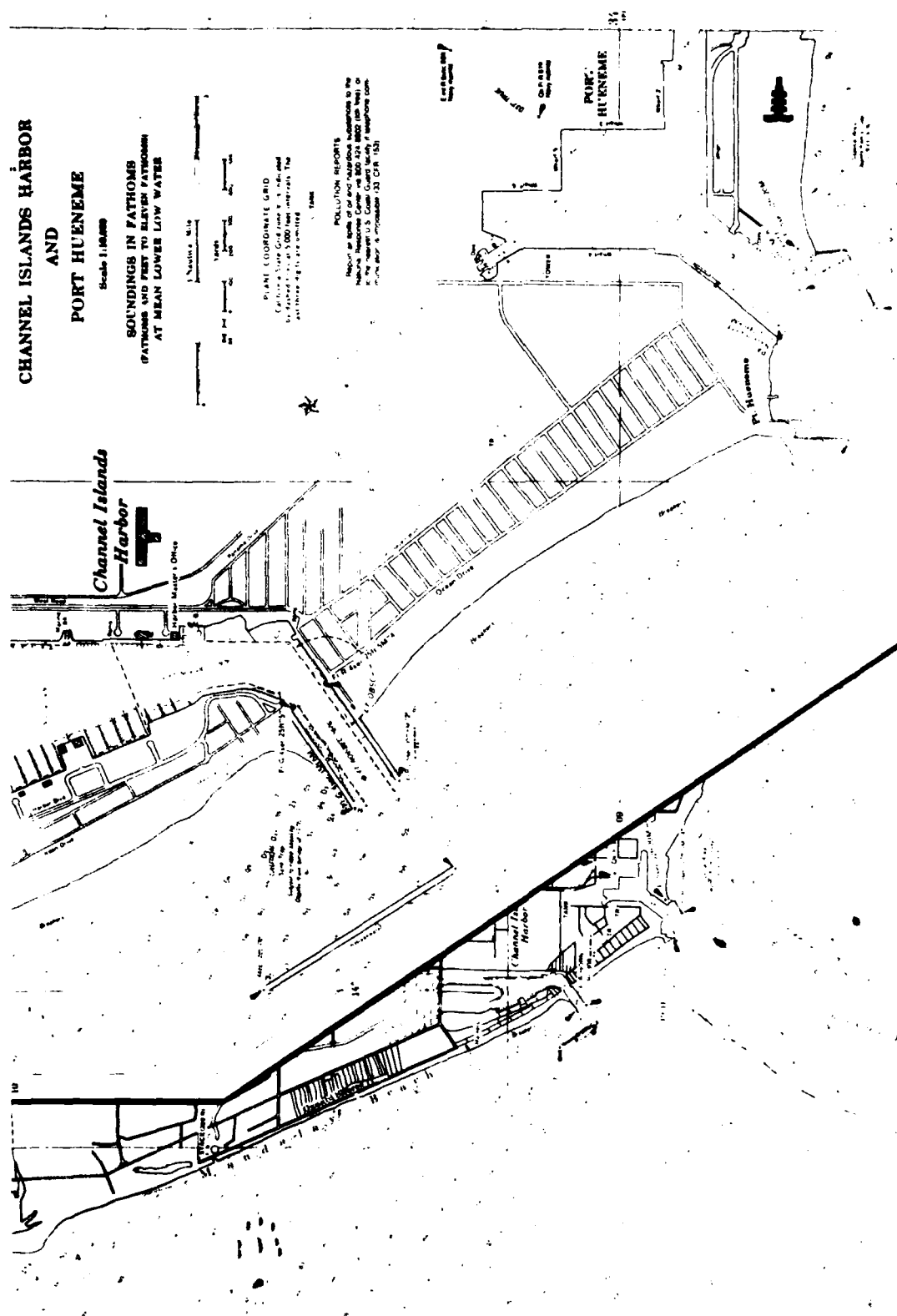


Figure 4. Molate Fuel Pier (from Dames and Moore, 1978; see Figure 1).



**Figure 5.** Port Hueneme Harbor area. Sand is dredged from Channel Islands Harbor and pumped to Port Hueneme beaches to bypass Port Hueneme Harbor (from NOAA Chart 18725).

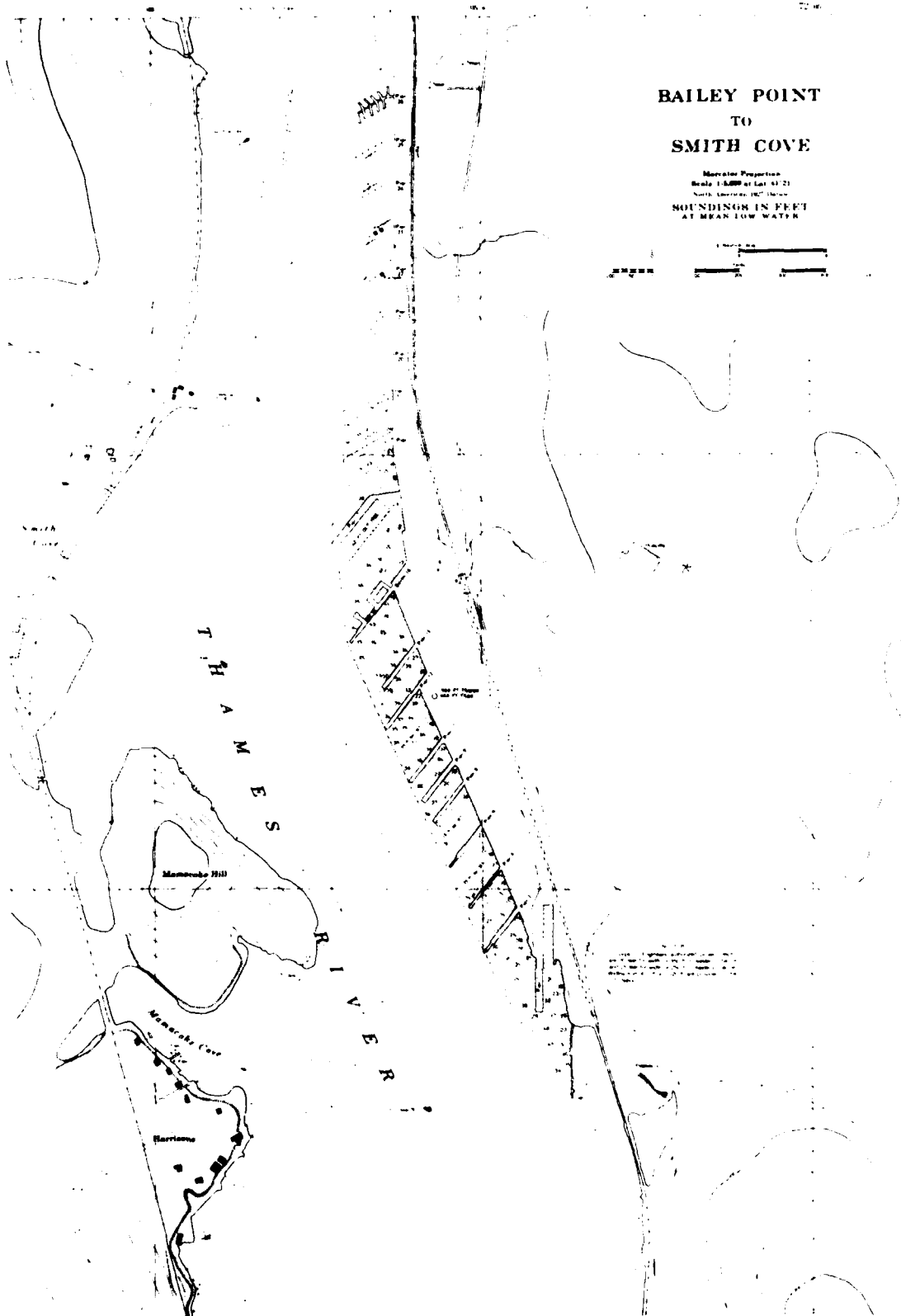


Figure 6. New London Naval Submarine Base (from NOAA Chart 13213).



Figure 7. Location map of Naval Weapons Station Earle (Figure 8)  
(from NOAA Chart 12327).

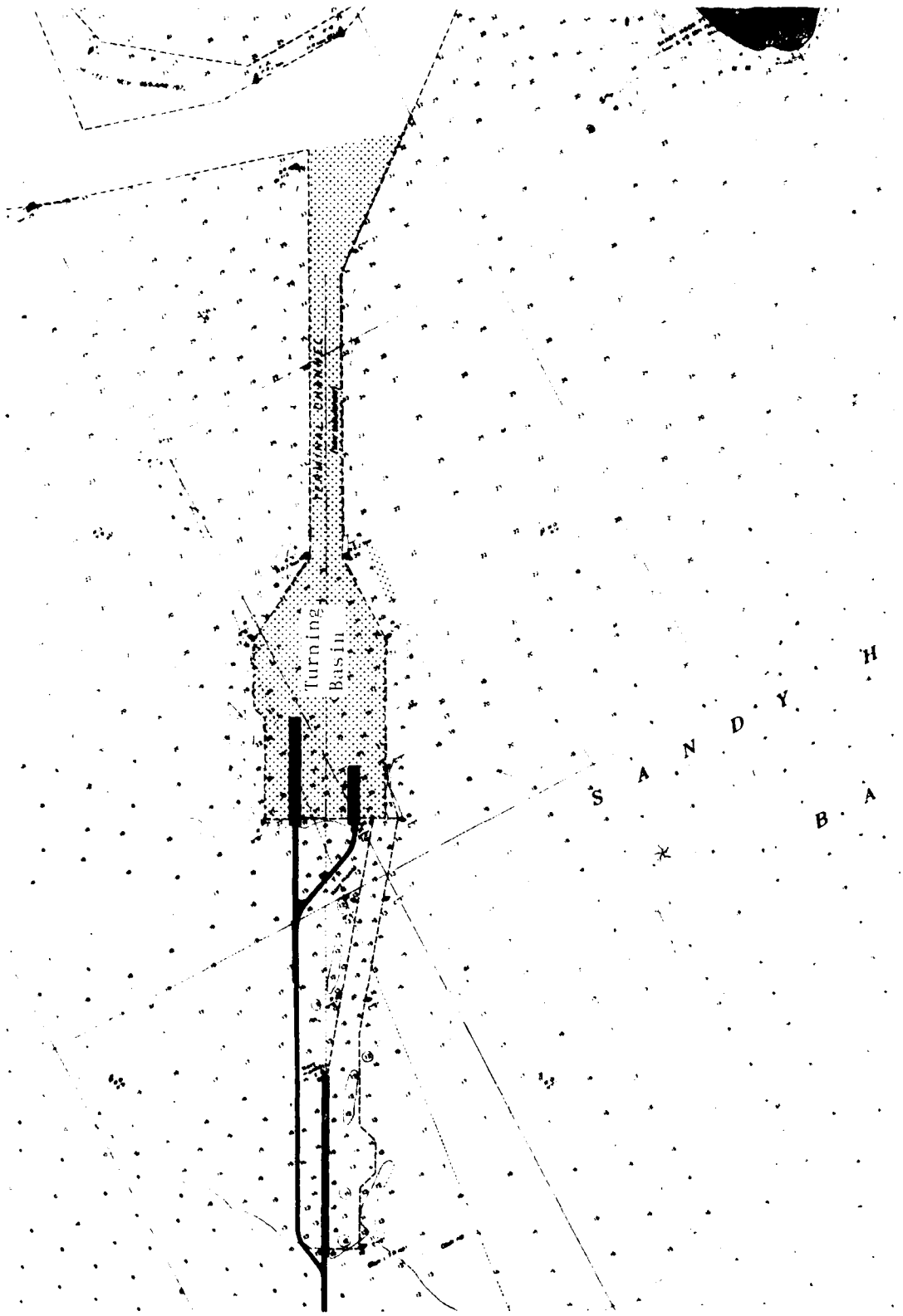


Figure 8. Naval Weapons Station Earle showing Leonardo Piers in Sandy Hook Bay  
(from NOAA Chart 12330; see Figure 7).

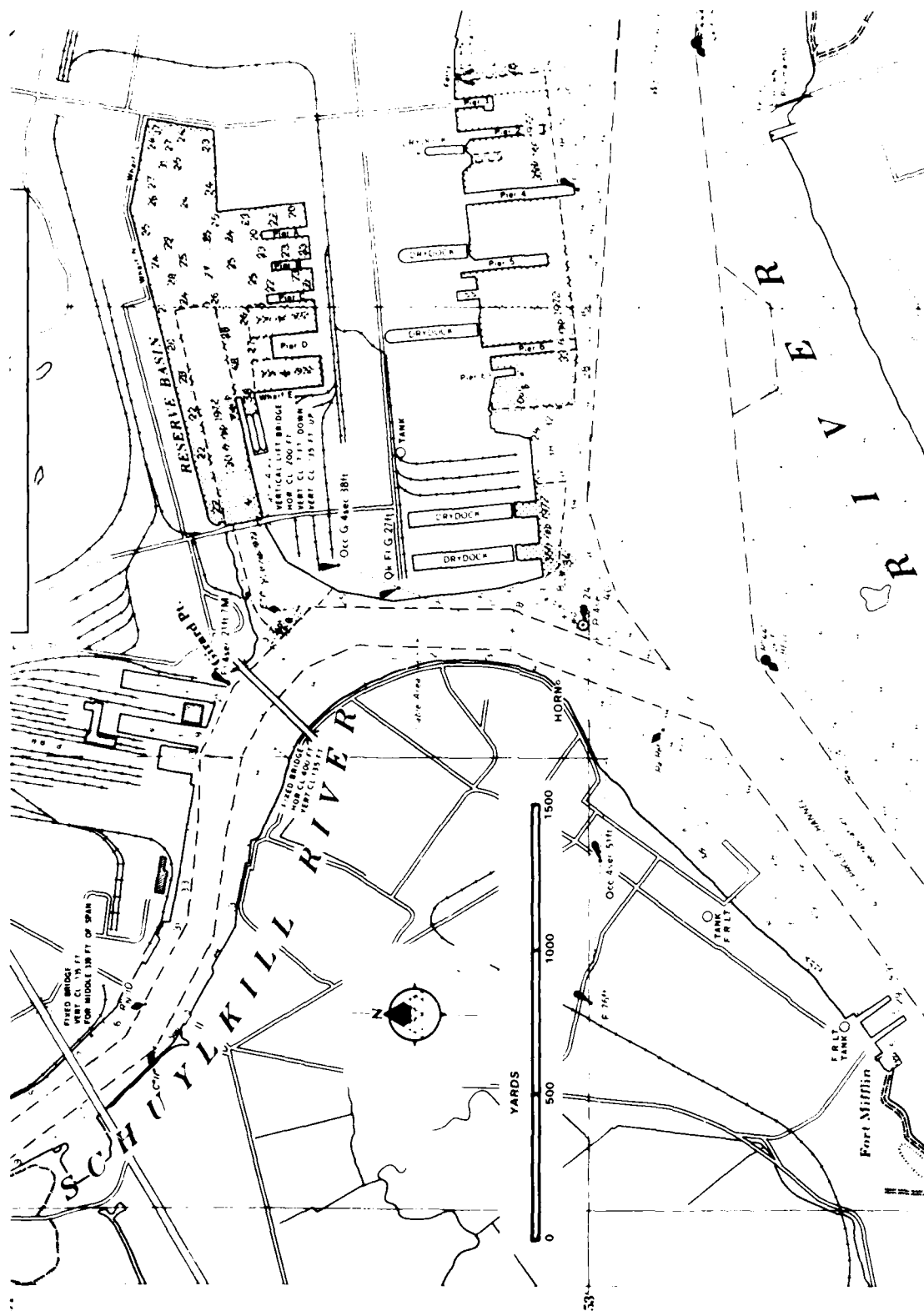


Figure 9. Philadelphia Naval Shipyard (from NOAA Chart 12313).

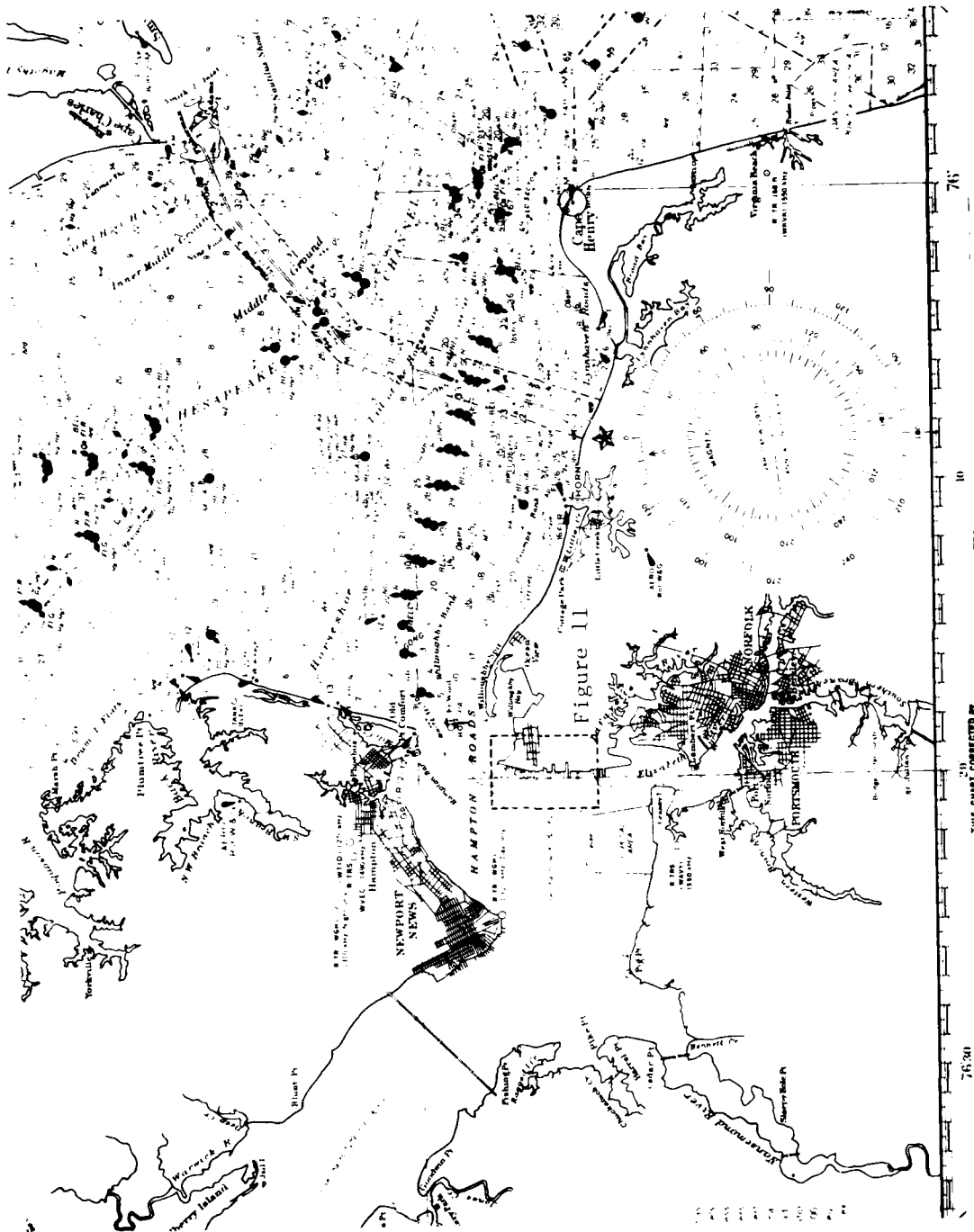


Figure 10. Location map of Norfolk Naval Station (Figure 11) (from NOAA Chart 12245).

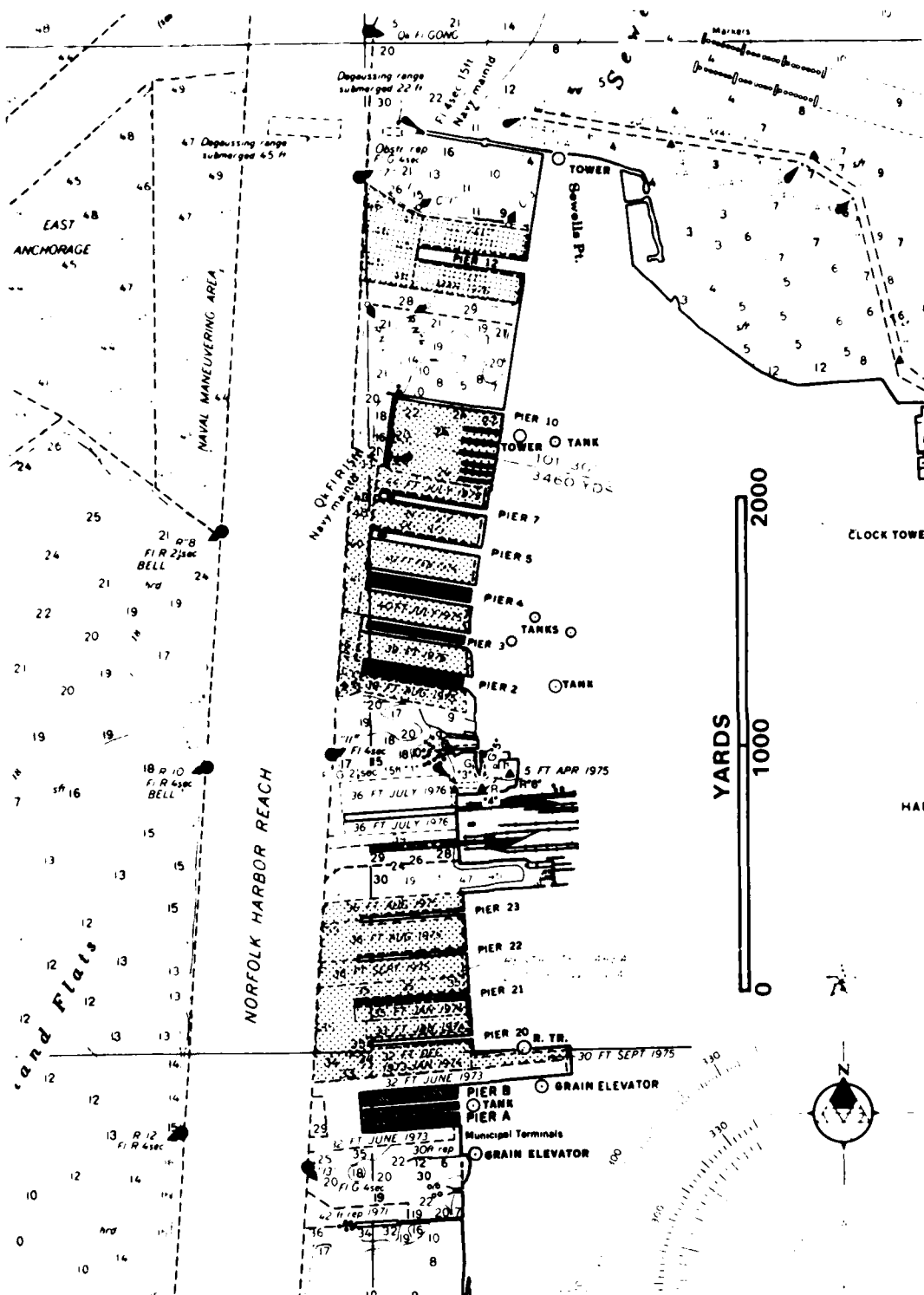


Figure 11. Norfolk Naval Station (from NOAA Chart 12245).

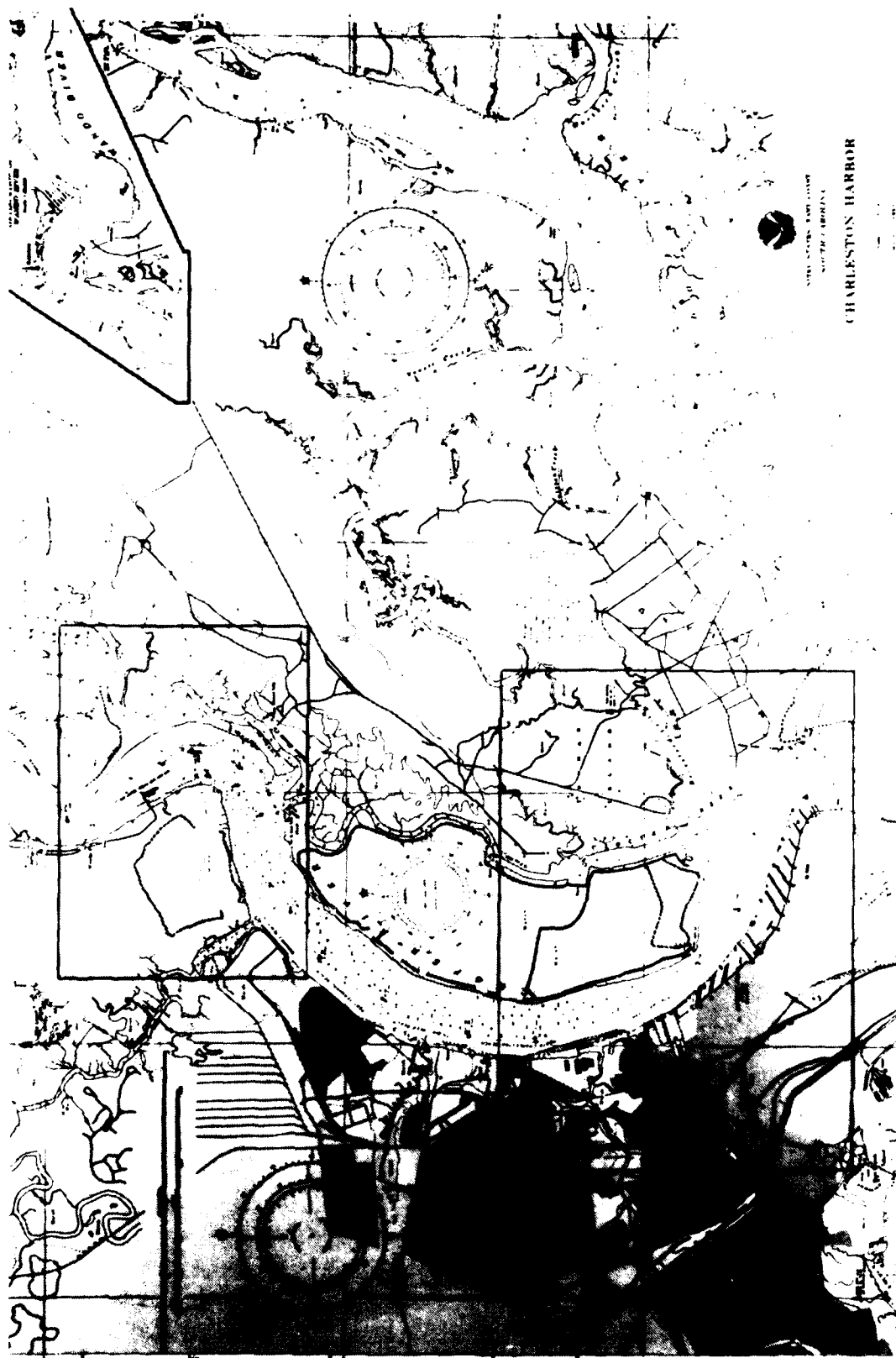


Figure 12. Location map of Charleston Naval Base (Figure 13) and the Naval Weapons Station area (Figure 14) (from NOAA Chart 11500).

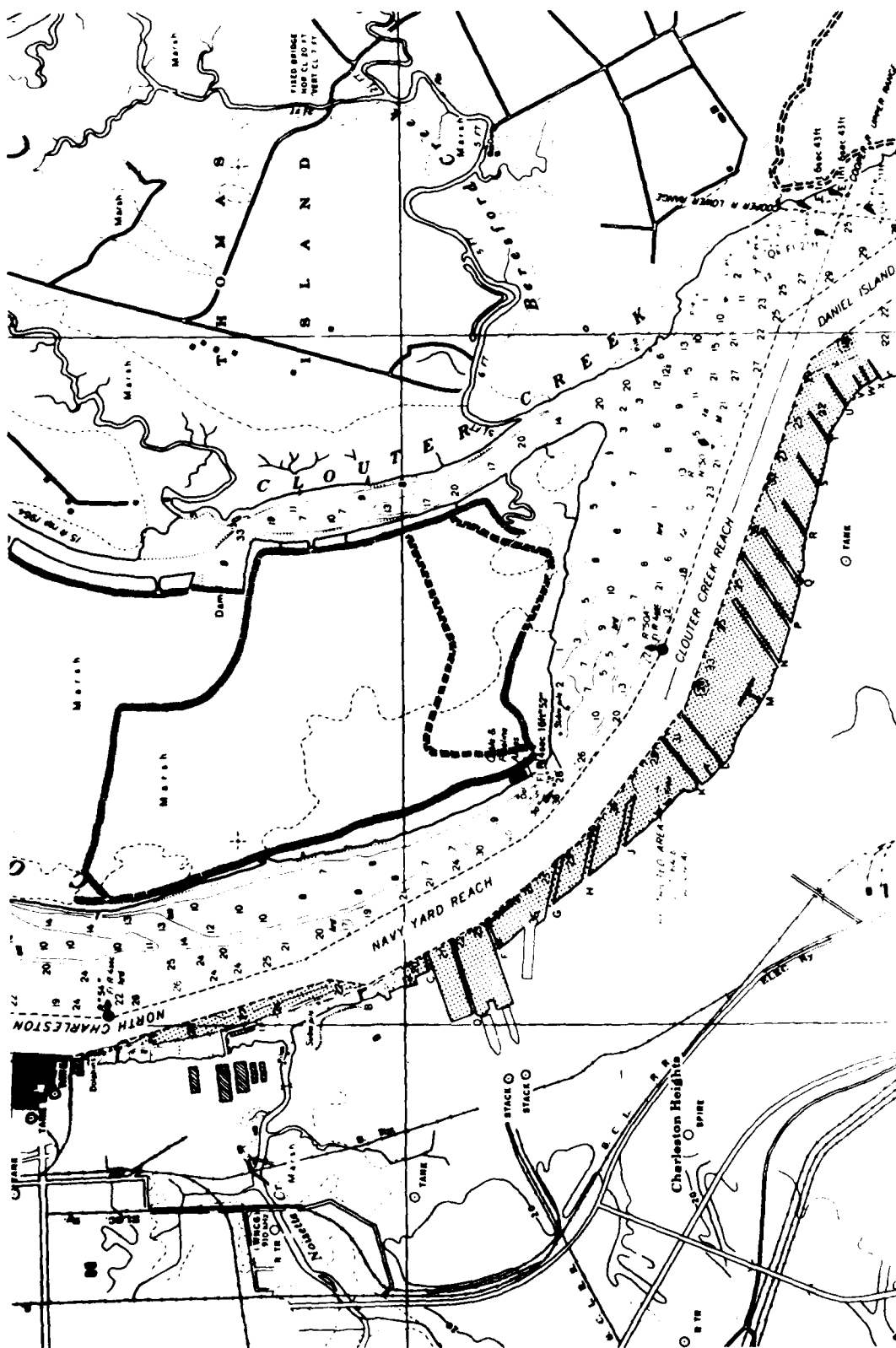


Figure 13. Charleston Naval Base (from NOAA Chart 11524).





Figure 15. King's Bay Trident Base. Cumberland Sound lies west of Cumberland Island (from NOAA Chart 11503).



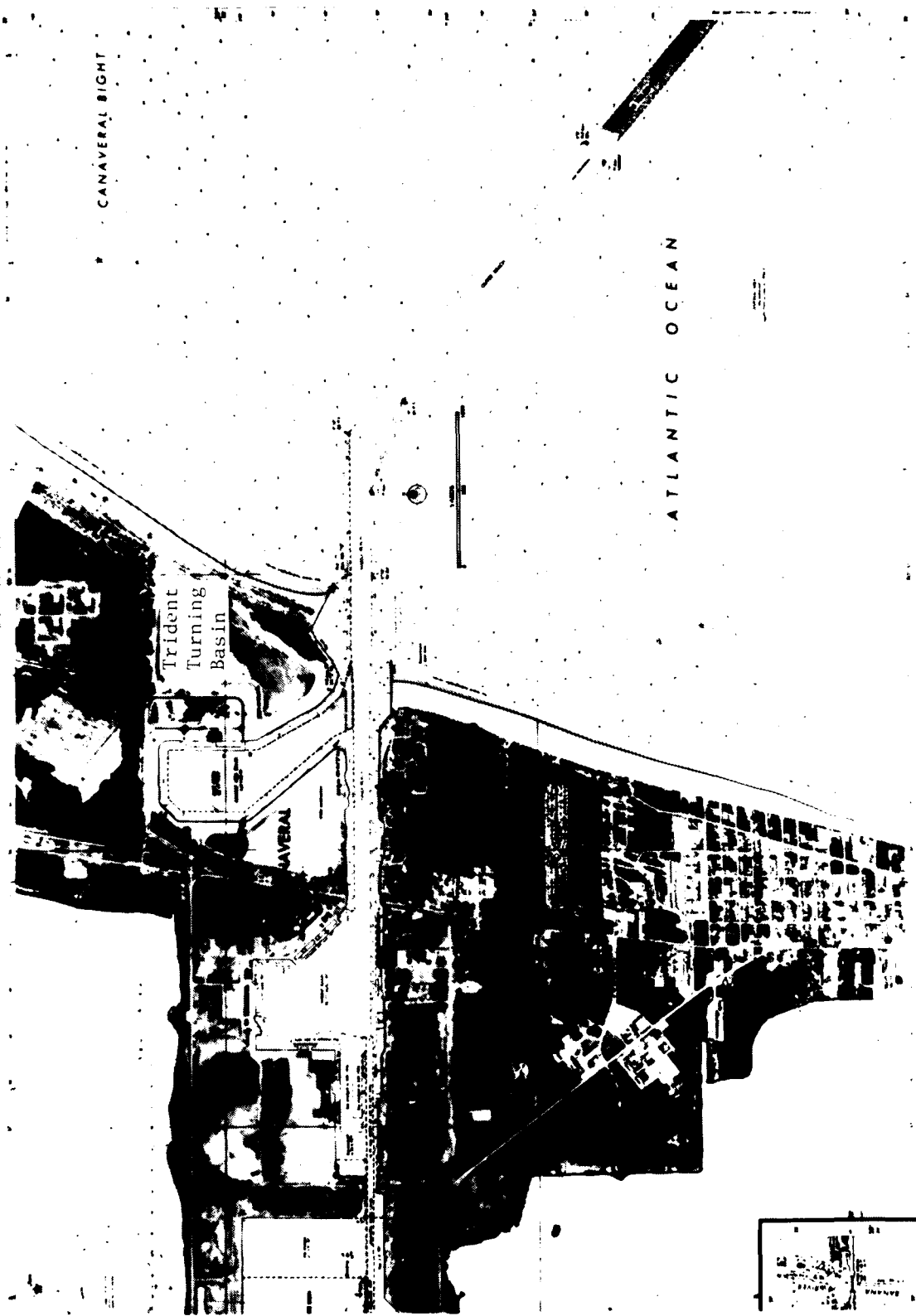


Figure 17. Port Canaveral Harbor (from NOAA Chart 11478).

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